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A Study on Code Sharing Policies of PLOS Journals in the Open Science Environment

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Abstract

Purpose: Taking the PLOS publishing organization and its journal series as an example, this study examines the code sharing policies of academic journals to provide reference and guidance for domestic journals in optimizing their open science policies. **Methods:** Through literature analysis and web-based survey methods, we review and analyze the evolutionary trajectory, main content, and development trends of PLOS code sharing policies. **Results:** PLOS code sharing policy has become independent from data policies, and its mandatory code availability statements and supporting policies have effectively increased the code sharing rate of published papers, facilitating research reproducibility and efficiency improvement. **Conclusion:** In the era of deepening open science development, compared with data policies, academic journal code sharing policies are still in their infancy. Development trends include coordinated development with data policies and adherence to and application of FAIR software principles, which provides valuable reference for Chinese academic journals to formulate code policies alongside data policies.

Full Text

Preamble

Research on Code Sharing Policies of PLOS Journals in an Open Science Environment

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Abstract

[Purposes] Taking PLOS (Public Library of Science) publishing institutions and its series of journals as examples, this study examines the code sharing

policies of academic journals to provide reference and guidance for domestic journals seeking to optimize their open science policies. **[Methods]** Through literature analysis and web-based investigation, we systematically analyze the evolutionary trajectory, main content, and development trends of PLOS code sharing policies. **[Findings]** PLOS code sharing policies have become independent from data policies, and their mandatory code availability statements and supporting policies have effectively increased the code sharing rate of published papers, thereby facilitating research reproducibility and efficiency improvements. **[Conclusions]** In the era of deepening open science development, code sharing policies for academic journals remain in their infancy compared to data policies. Development trends include coordinated evolution with data policies and adherence to FAIR software principles, offering valuable insights for Chinese academic journals to introduce code policies alongside existing data policies.

Keywords: open science; code sharing policy; academic journal; scientific software; open code; data policy

In the era of data-intensive and computation-intensive research paradigms, the value of data and its associated software and source code has become increasingly prominent, emerging as a primary focus of open science and open publishing [1]. In November 2021, UNESCO adopted the *Recommendation on Open Science*, marking the entry of open science into a new phase of global in-depth development. A notable feature of this phase is that following “open access” and “open data,” “open source code” has gradually become one of the pillars of open science [2]. Currently, countries and organizations such as France, the Netherlands, Australia, the European Union, and the Research Software Alliance (ReSA) are taking measures to promote the open sharing of scientific software, including building software repositories, implementing FAIR principles, and promoting software publishing [2-3].

Academic publishing has always been a key domain of the open science movement [4]. In recent years, several influential academic publishers and scholarly organizations have introduced code sharing policies alongside data sharing policies [5], including Springer Nature, PLOS, the European Geosciences Union (EGU), the American Geophysical Union (AGU), and the American Economic Association (AEA). Concurrently, academic research on the open sharing of scientific software/code has become increasingly active, covering topics such as software citation and academic impact assessment [2], FAIR software principles [3,6], software publishing platforms and their metadata [7], and publishing policies [8-10]. However, overall, domestic attention to the open sharing of software and code associated with academic papers remains insufficient, with research and practice seriously lagging behind the open sharing of scientific data. This has resulted in limited relevant achievements and is not conducive to the comprehensive, balanced, and sustainable development of open science practices in China’s academic publishing field.

The renowned publishing institution PLOS (Public Library of Science) is an active practitioner of open science. Its open access (OA) model, knowledge service platforms, and publishing operation experience have received continuous attention from Chinese scholars [11-13]. In fact, PLOS has also been at the forefront of “code sharing,” with its code policy having evolved into an independent publishing policy that has achieved initial success [8]. Using this as an entry point, this paper employs literature analysis and web-based investigation methods to systematically interpret the evolutionary trajectory, main content, and development trends of PLOS journals’ code sharing policies. We summarize typical cases and common patterns of “code availability statements,” analyze the guiding role of FAIR software principles, and aim to provide reference and guidance for Chinese academic publishing institutions to improve their academic journal publishing policies under the new circumstances of open science.

1 Evolution of PLOS Code Sharing Policy

“Scientific software,” also known as “research software” or “academic software,” is typically reused in the form of source code in open science environments [4]. While no unified definition has yet been established across all parties, the definition provided by ReSA is widely adopted [14-15], which states that scientific software encompasses source code, algorithms, scripts, computational workflows, and executable programs created during or for the purpose of research. UNESCO further defines “open software/code” as “software and its source code that can be publicly accessed, obtained, and reused by anyone” [14].

In publishing practice, PLOS has consistently emphasized the open sharing of scientific software and source code associated with academic papers, steadily elevating its status in open science practice. The evolution of relevant policies is illustrated in Figure 1 [Figure 1: see original paper].

Since launching its first open access journal, *PLOS Biology*, in October 2003, PLOS has emphasized that the open access license CC BY (Creative Commons Attribution) should be applied to all aspects of research: papers, data, and methods (including code) [16]. As open data is a key focus area of open science, early PLOS data policies (prior to March 3, 2014) stipulated that if new software or algorithms were central to a paper, authors were responsible for ensuring the software met “open source software” (OSS) requirements: (1) providing an appropriate open source license, such as BSD, LGPL, or MIT; and (2) storing source code in public repositories such as GitHub [17]. Subsequently, these provisions became the core content of the independent PLOS code sharing policy. In January 2016, PLOS introduced the “Contributor Role Taxonomy” (CRediT) in the author guidelines for all its journals, dividing author contributions into 14 categories, including conceptualization, writing, data curation, software development, and data visualization [18].

With the development of open science, the computational biology research community supported by PLOS gradually formed a positive culture of code sharing.

Research shows that 41% of papers published in *PLOS Computational Biology* in 2019 voluntarily shared code [19]. To further understand researchers' attitudes toward mandatory code sharing policies, PLOS guided the editorial board of *PLOS Computational Biology* to conduct a survey between September 2020 and March 2021, covering 8,306 potential respondents. The results indicated that 75% of respondents wanted to view code related to papers, with 70% believing this would help understand the paper content, 63% planning to directly verify or run the code, and 12% wanting to replicate the research with their own data. Additionally, 48% expressed interest in reusing or refactoring the code [20].

Driven by the research community, PLOS recognized the important role of “open code” : (1) supporting research reproducibility; (2) improving efficiency of subsequent related research; (3) demonstrating credibility of results; (4) increasing usability of achievements; and (5) enhancing citation potential of papers. Simultaneously, PLOS further clarified the meaning of “open code” as “releasing code developed for data collection, interpretation, or analysis purposes in scientific research to repositories under open access licenses, or sharing it as supporting materials for papers” [20].

Against this backdrop, starting March 30, 2021, PLOS implemented more standardized and stringent code sharing policies through *PLOS Computational Biology*. In December 2022, PLOS launched the “Open Science Indicators” (OSI) to evaluate open science practices in over 80,000 papers, using three metrics: data sharing, code sharing, and preprint support [21].

2 Main Content of PLOS Code Sharing Policy

Code sharing policy emerged from data sharing policy, and the two share many commonalities. Therefore, drawing on research findings regarding the framework and elements of academic journal data policies [22], we introduce the main content of the policy from four aspects: code sharing requirements, software paper structure, code availability statements, and software storage rules. It should be noted that due to the unique characteristics of software that differ from data [3], the specific content of code policy also differs significantly from data policy.

2.1 Software and Source Code Sharing

The *Materials, Software and Code Sharing Policy* issued in March 2014 is a publishing policy parallel to the *Open Data Policy*, applicable to all 12 journals under PLOS [23].

When software is central to a paper, the policy expects: (1) authors to share all relevant software without restrictions upon publication; (2) authors to ensure software availability for a certain period regardless of version upgrades; and (3) authors to provide reasonable copies if the original software cannot be shared. Similar to the “minimal dataset” in data policies [5], software manuscripts submitted by authors must meet basic requirements: (1) software complies with the open source definition and standards of OSI (Open Source Initiative); (2)

software source code, installation and operation instructions, and test datasets are preserved in open software repositories; (3) software-related documentation is provided in the paper' s “Supporting Information” section and will undergo peer review; and (4) the paper includes links to the software' s location in the repository.

To further promote code sharing and reuse, the policy also provides recommendations: (1) assign a persistent identifier (PID), such as DOIs (Digital Object Identifiers), to code in repositories; (2) describe in detail the dependencies between codes through documentation; and (3) provide access methods and approaches for obtaining code in the paper' s “Data Availability Statement” (DAS) section.

If code cannot be shared due to legal or ethical reasons, authors should state this in the DAS and detail how to obtain the code through application. In cases where code cannot be shared, editors and reviewers reserve the right to access the code if they deem it necessary for comprehensive evaluation of the manuscript.

If software or algorithms are not central to the paper, PLOS also encourages authors to share all relevant materials free of charge, including software and its source code.

2.2 Software Papers

PLOS journals including *PLOS Climate*, *PLOS Global Public Health*, *PLOS Water*, and *PLOS Computational Biology* support authors in publishing “software papers” that describe an open-source software tool with broad utility representing a significant advance in generating new biological insights. Among these, *PLOS Computational Biology* launched a “Software Section” in August 2011 to collect software papers published in the journal. In May 2012, *PLOS Computational Biology* clarified the structural requirements for software papers, detailed in Table 1 [24].

Table 1 Structure of Software Papers

Section	Description
Title	Article title includes the software name
Introduction	Introduces the tasks implemented by the software, particularly the new biological insights that can be obtained
Design and Implementation	Describes the problem solved by the software and its novelty and specificity in solving that problem

Section	Description
Results	Provides examples of biological problems solved using the software, including results obtained under test data and relevant parameters
Availability and Future Directions	Provides software storage location and licensing information, authors' future work plans, and suggestions for how others can extend the software
Data Availability Statement	Like general research papers, provides storage locations and access methods for all data required to reproduce the research
Supporting Information	Provides test data and parameters for the software, and descriptions of how to install and run the software

Like general research papers, authors submitting software papers must simultaneously submit source code, binary executable programs, test data, and operation documentation. The prerequisite for publishing a software paper is that editors or reviewers can reproduce research results using the software, data, and parameters provided by the authors.

2.3 Code Availability Statement

The “Data Availability Statement” (DAS) has promoted the standardization and normalization of journal data sharing mechanisms and has become an important component of academic journal data policies, including those of PLOS journals [25,26]. Similarly, to improve existing policies, *PLOS Computational Biology* introduced a new code sharing policy in March 2021, with its core being the “Code Availability Statement” (CAS) [27].

Key points of the new policy include: (1) all new papers submitted to the journal after March 30, 2021 must share all relevant code unless exempted from the policy for legal or ethical reasons; (2) code availability must be declared in the paper' s DAS section, with code recommended to be preserved in public repositories under open source licenses; (3) code executed in commercial software packages (such as Matlab, SPSS, and office software) must also be shared, with version information of commercial packages included in the DAS; (4) any restrictions on code sharing must be stated in the DAS and are subject to editorial evaluation; (5) software should be cited properly, with code having PIDs included in references; (6) authors are responsible for code quality; (7) for software papers, the prerequisite is to store code in repositories capable of remote execution or provide detailed documentation for installing and using the software; and (8) peer reviewers are required to assess authors' compliance with the policy and can review the code themselves.

The basic content of CAS is the location or method for accessing shared code, with richer code availability information provided whenever possible, such as open source licenses, dependency packages, and related data. Through investigation of actually published papers, the main content categories of CAS and example texts are shown in Table 2 .

Table 2 Content Categories of Code Availability Statement (CAS)

Category	Example Text
Data and code stored in same software repository	All data and code supporting reproducibility are available at https://github.com/organic-chemistry/repli1D
Data and code stored in same data repository	Data and code are stored at https://doi.org/10.5281/zenodo.6378376
Data and code stored separately	Code archived at https://github.com/SamuelBrudner/juvenile_{{syllable}}_{{analysis}} , data available via DOI: 10.7924/r4j38x43h
Code only, no data	Open source software tool located at https://github.com/marcottelab/whatprot , version v1-updated; no new data generated in this study
Code stored in multiple repositories	Code stored separately at https://simtk.org/projects/musc_{{regen}}_{{abm}} and https://github.com/stkhuu/muscleRegen.git
Code in “Supporting Information” files	Code required to reproduce the study provided as supporting material, see files MakeFigs.m and MakeFigS3.m in “Supporting Information”
Code stored in repository with DOI	All code stored in GitHub and assigned DOI using Zenodo: https://doi.org/10.5281/zenodo.7727880
Dependency package access methods	1) swga2.0 program and all dependencies available in conda environment from https://anaconda.org/janedwivedi/swga2 ; 2) Code runs on OpenFOAM v6, available at https://openfoam.org/version/6/
Code in public repository requiring application	NeMoCAD code stored at https://doi.org/10.5281/zenodo.7692712 , access requires application; application documentation available in “Supporting Information”
Code cannot be shared	Source code cannot be provided due to ethical restrictions (Ethics Protocol B322201630276)

Category	Example Text
Using mature software	1) Software Rosetta used, version ad2739a, free for academic community, download and install via https://www.rosettacommons.org ; 2) R-CNN trained using Python 3.7.3; 3) Visualization using open source tool ParaView (www.paraview.org)
Open source license description	1) Code used under GPL3 license; 2) R package stored in GitHub under MIT license
Publishing public software packages	HAL-x software uploaded to PyPI (Python Package Index): https://pypi.org/project/hal-x/

In April 2022, PLOS collaborated with the open-source project DataSeer to investigate and evaluate the policy's implementation after one year [8]. The results showed that for papers published in *PLOS Computational Biology* between January 2019 and March 2022, over 99.5% generated code supporting the research, making sharing possible. Thanks to the new policy, the code sharing rate for newly submitted and published papers reached 87% between April 2021 and March 2022, significantly higher than the 61% rate for all of 2020. Notably, the proportion of papers sharing code through CAS in the DAS increased significantly in 2021 to 78%, compared to 58% in 2020. According to a new survey, by September 2023, the code sharing rate for papers had further increased to 96%, prompting the editor-in-chief to establish code sharing as a permanent feature of the journal [28].

2.4 Public Repositories

Both data sharing and software sharing rely on the support of public repositories. PLOS's basic requirement for software repositories is that they have been operating for more than five years or host over 1,000 projects [23]. With the introduction of the new software sharing policy, PLOS has proposed new requirements for public repositories used by authors [27], mainly: (1) ability to provide DOIs or other PIDs for source code; (2) support for software version control; (3) support for software citation; (4) if standards for software preservation exist in a discipline, authors must select repositories that comply with those standards; (5) recommendation to use professionally or generally recognized repositories approved by academic communities; and (6) data and software can be stored together or separately.

PLOS provides a list of recommended repositories for authors, with partial results shown in Table 3 [29]. In environmental and biomedical fields, PLOS recommends using standard repositories indexed by the renowned registries FAIR-sharing (<https://fairsharing.org/>) and Re3Data (<https://www.re3data.org/>).

Table 3 Partial List of Software Repositories Recommended by PLOS

Repository	URL	Description
GitHub	https://github.com/	General open-source software hosting platform
Code Ocean	https://codeocean.com/	General platform for creating, publishing, preserving, and reusing executable code and data
SourceForge	https://sourceforge.net/	General open-source software development platform and repository
Software Heritage	https://www.softwareheritage.org/	Software heritage.org/archive maintained by UNESCO and France
Zenodo	https://zenodo.org/	Comprehensive open science repository
Figshare	https://figshare.com/	Comprehensive open science repository
OSF	https://osf.io/	Platform helping researchers share their work
Bioinformatics.org	http://www.bioinformatics.org/	Open-source software platform for bioinformatics
PhysioNet	https://physionet.org/	Medical software and data sharing platform managed by MIT Laboratory for Computational Physiology

According to PLOS surveys, approximately two-thirds of authors currently store and share code through GitHub [8]. GitHub is the world’s largest code hosting platform, gathering over 70 million developers. As early as 2014, GitHub partnered with Zenodo to assign DOIs to software, supporting software citation and publishing [30]. When source code is provided as “Supporting Information” along with the manuscript, PLOS stores it in the Figshare repository [27].

3 Development Trends

3.1 Coordinated Development of Code Sharing and Data Sharing

Among the various new research objects of concern in open science, data and software have the closest relationship. To fully achieve data sharing, related resources and research outputs also need to be shared, including software, algorithms, instruments, and materials [31]. Broadly speaking, software and code are also a form of data. Therefore, many publishing institutions’ code sharing policies are included within data policies, such as those of Elsevier and Wiley. With the development of open science, the multiple unique attributes of scientific software that distinguish it from scientific data have been identified, such as

executability, version control, and dependency relationships, making its open sharing no less important than data [6]. In addition to PLOS, an increasing number of organizations and institutions have introduced software and code sharing policies (see Table 4), treating software as a scientific object distinct from data.

Table 4 Publishers and Academic Organizations with Code Sharing Policies

Publisher/Academic Organization	Journals Covered	Policy Features
Nature Portfolio (Springer Nature)	181 journals	Mandatory code and algorithm availability statements; some journals require code peer review
BMC (Springer Nature)	~300 scientific and medical journals	Storage location and access methods for new code stated in “Data and Materials Availability Statement”
European Geosciences Union (EGU)	<i>Geoscientific Model Development</i> (one journal)	Mandatory “Code and Data Availability Statement” requiring sharing of both code and data related to papers
American Geophysical Union (AGU)	23 AGU journals	Mandatory “Software Availability Statement” and software citation
American Economic Association (AEA)	8 AEA journals	Data and code availability policy encouraging software citation

These policies all require code availability statements (CAS), but the specific declaration patterns vary across journals and papers (see Table 5). Most emphasize “data availability,” while a few highlight “code availability” or list both side

by side. Regardless of the pattern, all aim to ensure synchronized open sharing of code and data, striving for the optimal open science effect of “1+1>2,” which is precisely what PLOS OSI advocates [21]. To this end, ReSA has partnered with FORCE11 (Future Of Research Communications and E-Scholarship) to establish a “Code Availability Working Group” dedicated to coordinating various publishing institutions and standardizing and promoting consistent code and data sharing policies [32].

Table 5 Common Patterns of Code Availability Statement (CAS)

Pattern	Description
Data Availability Statement (DAS)	Both data and code availability statements placed in DAS, as in PLOS journals and AGU journals
Code Availability Statement (CAS)	CAS only, as in Nature’ s data journal <i>Scientific Data</i>
Code and Data Availability Statement (CDAS)	Both code and data availability statements placed in CDAS, as in some papers in EGU’ s <i>Geoscientific Model Development</i> where data availability is already described separately
DAS and CAS coexist	Papers contain both DAS and CAS, declaring data and code availability separately, as in Nature’ s <i>Nature</i> and PLOS software papers

In the process of building high-level Chinese scientific journals, great importance has been attached to the formulation and implementation of data sharing policies [22,33]. Surveys show that among the leading journals selected for the “Excellence Action Plan of Chinese Science and Technology Journals,” nearly 82% have introduced data policies, while this proportion exceeds 34% for tier journals [33]. Some journals’ data policies include content encouraging code sharing, such as the data paper template of *Biodiversity Science*. Therefore, under the current favorable conditions of data sharing in Chinese scientific journals, timely introduction of code sharing policies (especially CAS) to promote coordinated development of data sharing and software sharing and unleash the enormous potential of open science should be a natural progression and general trend.

3.2 Open Publishing Guided by FAIR Principles

The FAIR principles—Findable, Accessible, Interoperable, and Reusable—have been established by UNESCO’ s *Recommendation on Open Science* as one of the fundamental principles of open science. Originating from the need to standardize scientific data management in the open science era, the FAIR principles

have now been extended to software, hardware, and research workflows [3,6].

Following and applying FAIR principles has become a consensus in the publishing community regarding scientific data sharing and publishing [34,35]. PLOS has improved compliance with FAIR principles for data sharing through partnership with the Figshare repository [17], and its newly launched “Open Science Indicators” (OSI) were developed under the guidance of FAIR principles, primarily involving FAIR data principles and FAIR software principles [21].

The FAIR software principles were jointly developed by the Research Data Alliance (RDA), ReSA, and FORCE11, with the official version released in March 2022 [3,6]. The main content is shown in Table 6. In May 2022, the American Geophysical Union (AGU), in collaboration with the European Geosciences Union (EGU) and CERN, launched the “Community FAIR” project aimed at improving the FAIRness of data and software in academic communities and publishing fields [36].

Currently, PLOS code sharing policy support for FAIR software principles remains limited (see Table 6), particularly regarding insufficient emphasis on FAIRification of software metadata, leaving considerable room for improvement.

Table 6 FAIR Software Principles and PLOS Support Status

FAIR Principle Content	PLOS Support Status
Findable: Software and its metadata are easily discoverable by humans and machines	
Software is assigned a globally unique and persistent identifier	Supported
Software is described by rich metadata	Partially supported
Metadata explicitly includes the identifier of the software it describes	Partially supported
Metadata conforms to FAIR data principles and is searchable and indexable	Partially supported
Accessible: Software and its metadata can be retrieved through standardized protocols	
Software can be retrieved through standardized communication protocols via identifiers	Supported
Metadata remains accessible even when software is no longer available	Not supported
Interoperable: Software can exchange data and metadata through standard APIs	

FAIR Principle Content	PLOS Support Status
Software meets domain-relevant industry or community standards when reading, writing, and exchanging data	Partially supported
Software includes qualified references to other objects	Partially supported
Reusable: Software is both usable and reusable—understandable, modifiable, and rebuildable	
Software is described with multiple accurate and relevant attributes, including: (R1.1) software has clear and accessible license information; (R1.2) software is associated with detailed provenance information	Supported
Software includes qualified references to other software	Partially supported
Software and its documentation, APIs, etc. meet domain-relevant industry or community standards	Partially supported

Integrating the concepts of FAIR principles, China has successfully developed the national standard *Metadata for Data Paper Publication* (GB/T 42813-2023), which was implemented on August 6, 2023, significantly contributing to promoting scientific data open sharing and fully releasing data value [37]. Similarly, adapting to international development trends, China should promptly develop and implement metadata standards and specifications for software publishing. This would not only ensure the FAIRness level of scientific software but also effectively coordinate synchronized open sharing of data and software.

4 Conclusion

The intersection and integration of academic publishing and open science are driving innovation in research models and scholarly communication modes. UNESCO's *Recommendation on Open Science* establishes international norms and standards, committed to breaking the imbalance in open science development among countries and regions, and addresses imbalances among various research objects, particularly the lag of “open software sharing” behind “open data sharing.” The prominent manifestation in academic publishing is the independence of code sharing policies from data policies, with leading institutions including PLOS, Springer Nature, EGU, and AGU. Using PLOS as an example, this paper systematically introduces the evolutionary trajectory, main content, and implementation effects of its code sharing policy, and further analyzes development trends by synthesizing developments across various institutions. The paper has

limitations: (1) insufficient analysis of disciplinary differences in code sharing; and (2) no investigation or analysis of actual open source license usage.

Although PLOS' s code sharing policy has achieved initial success, it remains in its infancy and development stage compared to data policies [8]. Issues requiring in-depth exploration include: software copyright and privacy protection, source code review, and open source license compliance and conflicts, which will be the main directions for future research and attention.

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Author Contributions

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